Centre for Doctoral Training - Data Intensive Science

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UCL

The Probability of Mantle Plumes in Global Tomographic Models

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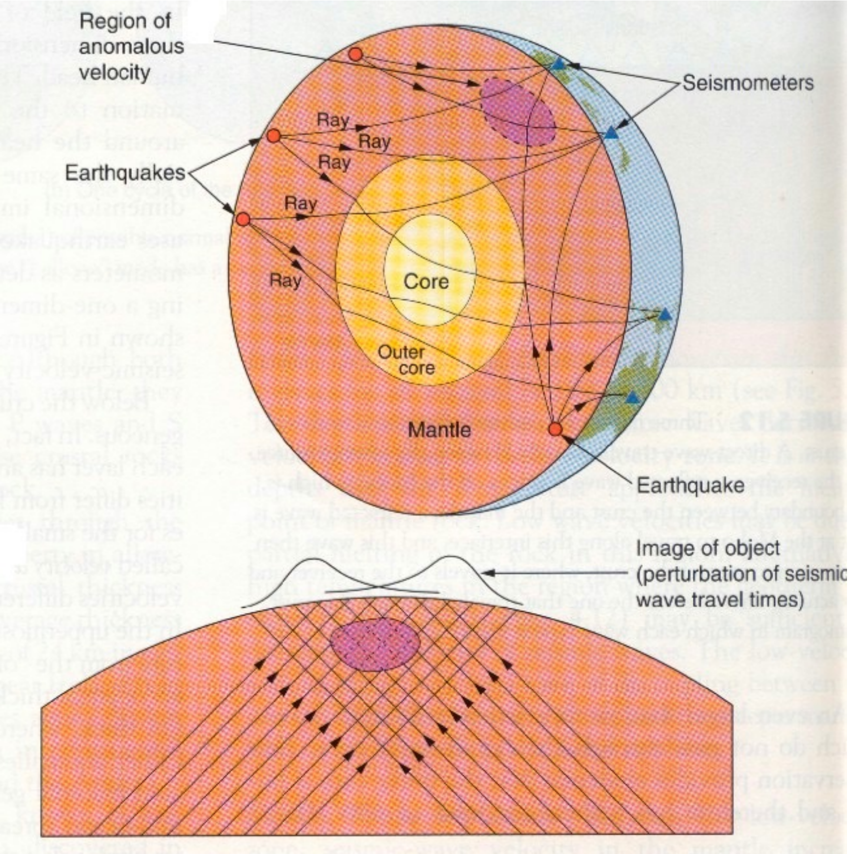
Introduction

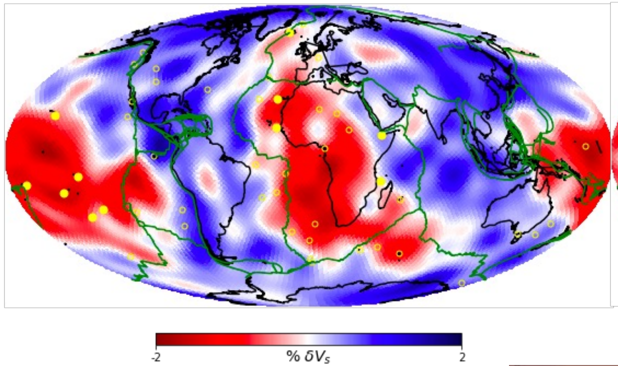
The state of seismic tomography

- Massive amounts of data
  - But not well distributed…
- Loads of tomographic models
  - Limited resolution
  - Uncertainties not generally reported
  - Inconsistent

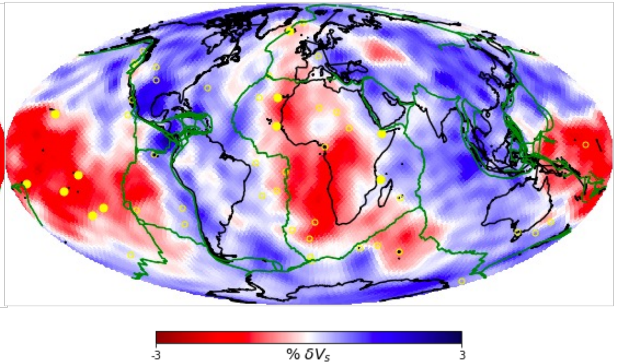


Introduction

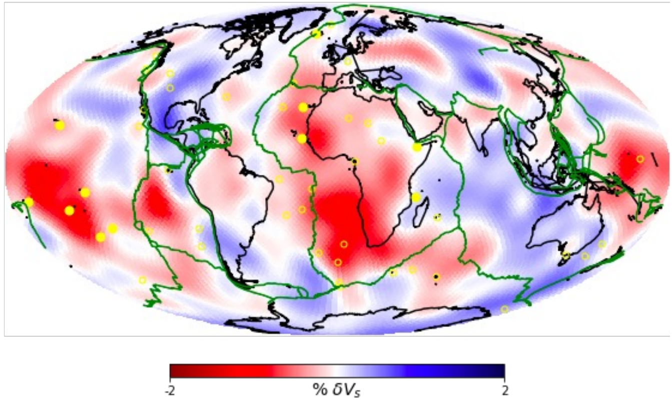
S20RTS 2800 km



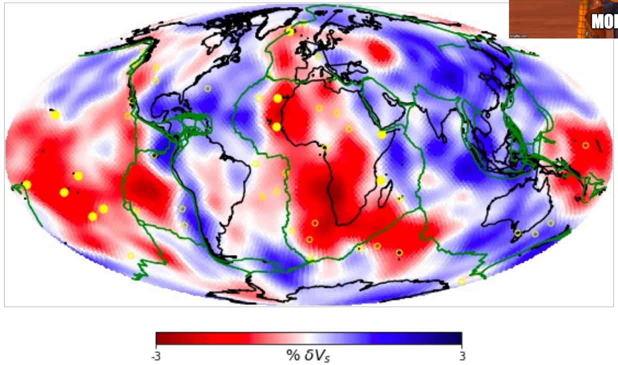
S40RTS 2800 km



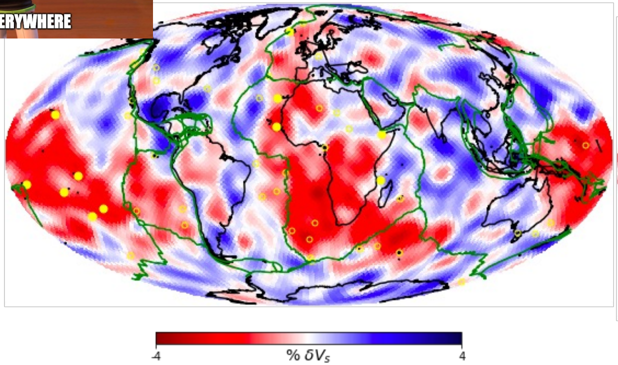
S362WMANI+Mi 2800 km



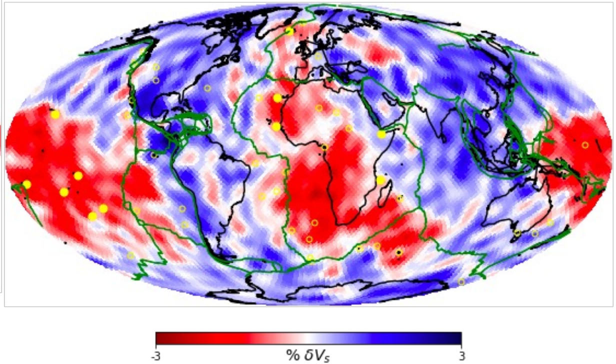
SAVANIi 2800 km



SEMUCBi 2800 km



SGLOBEi 2800 km



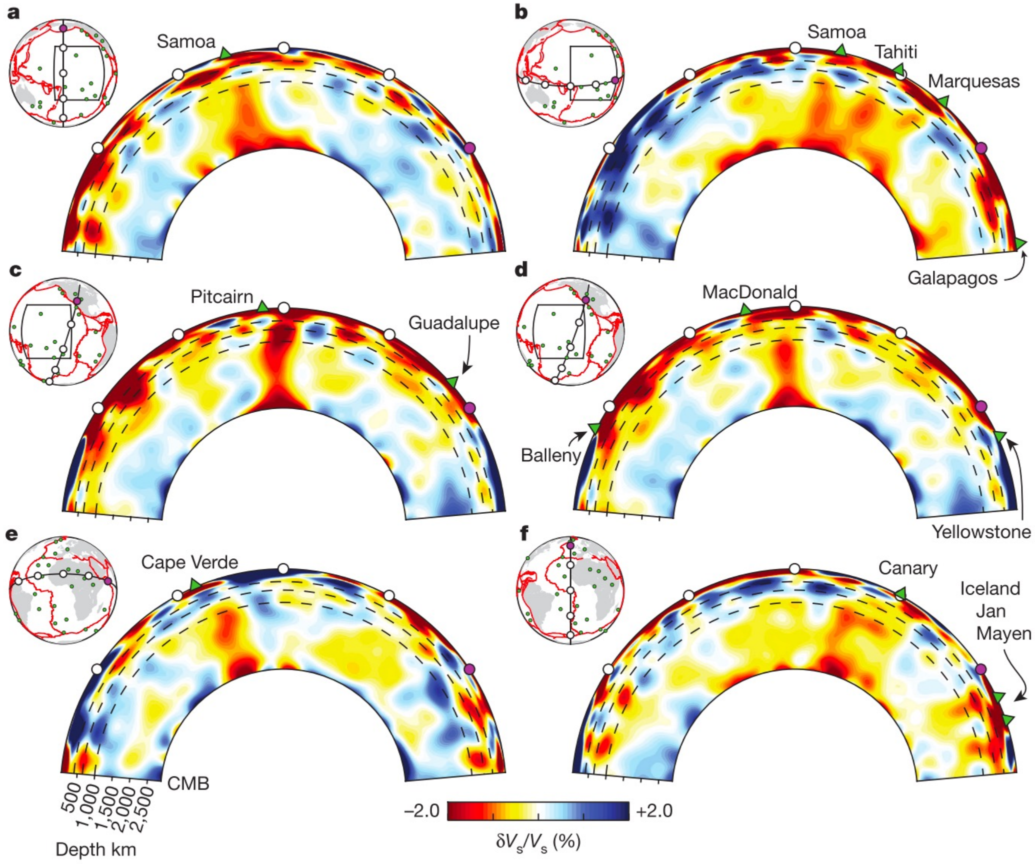
Introduction

Mantle Plumes

- Long, thin structures
- Maybe rooted in LLSVPs
- Often at the limit of horizontal resolution, particularly at depth

Questions:

- What is the probability of plumes in the models?
- Are features just noise or artefacts?
- Which features are consistent between models?



French & Romanowicz, 2015

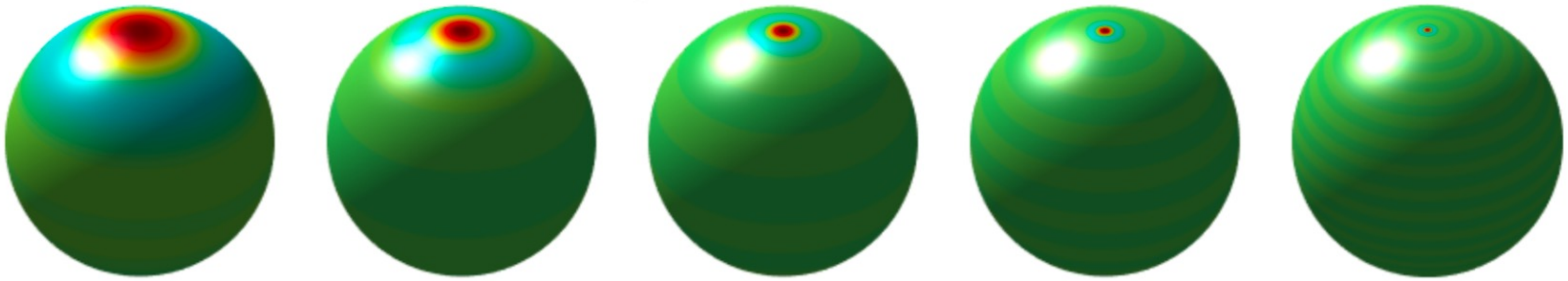
Method

Monte Carlo Simulations/Noise Realisations

- Assume that what you observe is one sample of a distribution
- Simulate a whole bunch of samples from that distribution
- Do some stats

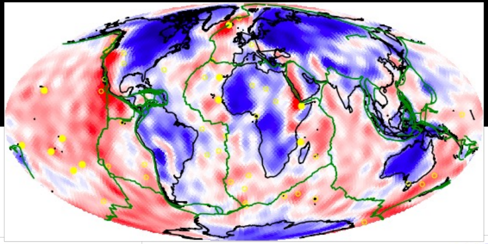
Spherical Wavelet Transform

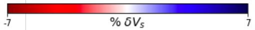
- Basically a Fourier Transform, but you keep location information
- Shows you where the large and small scale information is



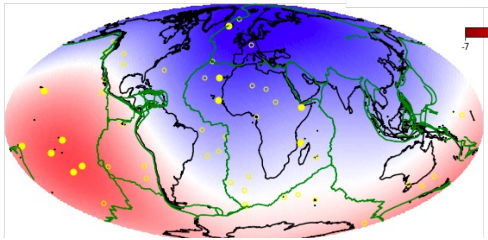
Method

SWT

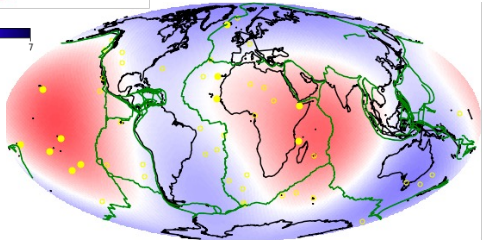




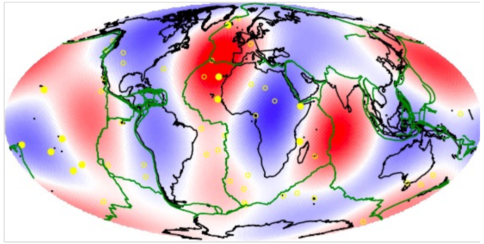
Scaling function



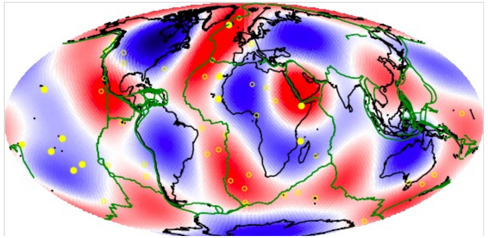
Wavelet scale: 1



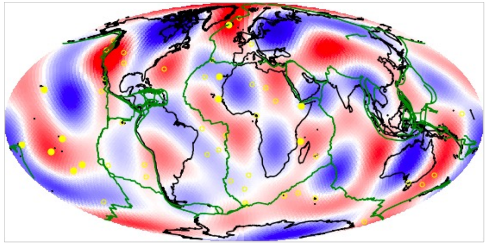
Wavelet scale: 2



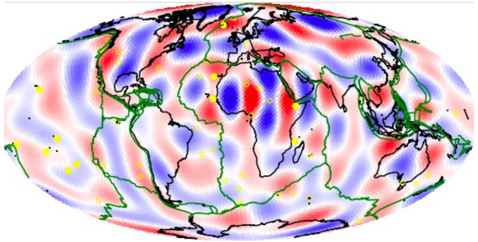
Wavelet scale: 3



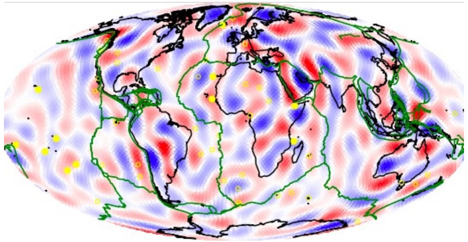
Wavelet scale: 4



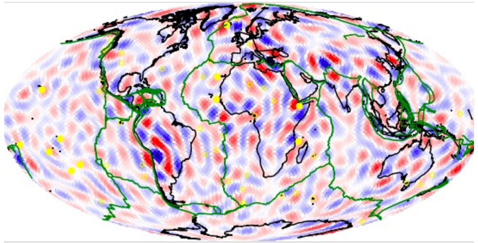
Wavelet scale: 5



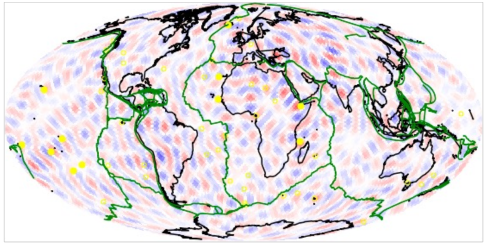
Wavelet scale: 6



Wavelet scale: 7

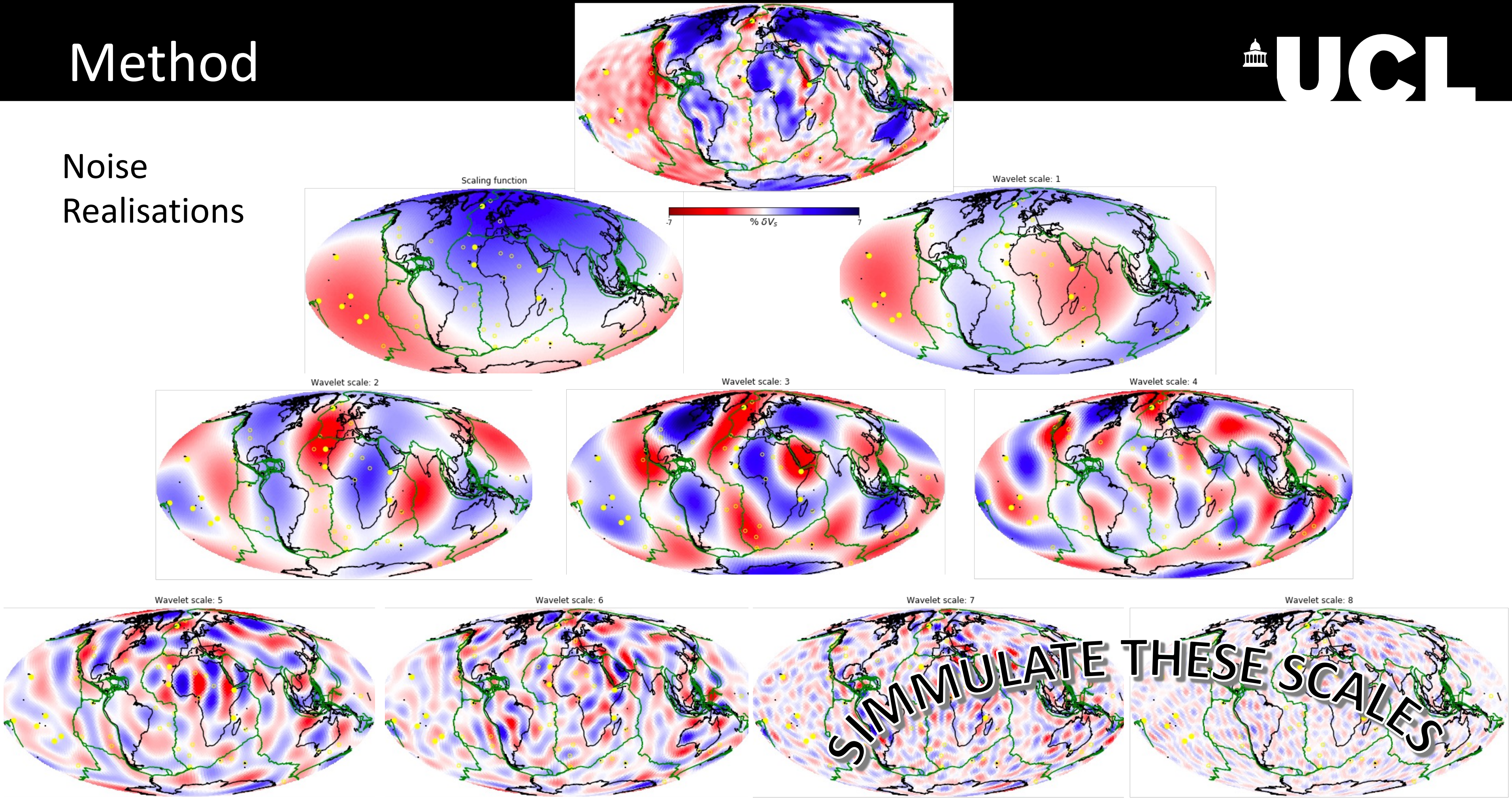


Wavelet scale: 8



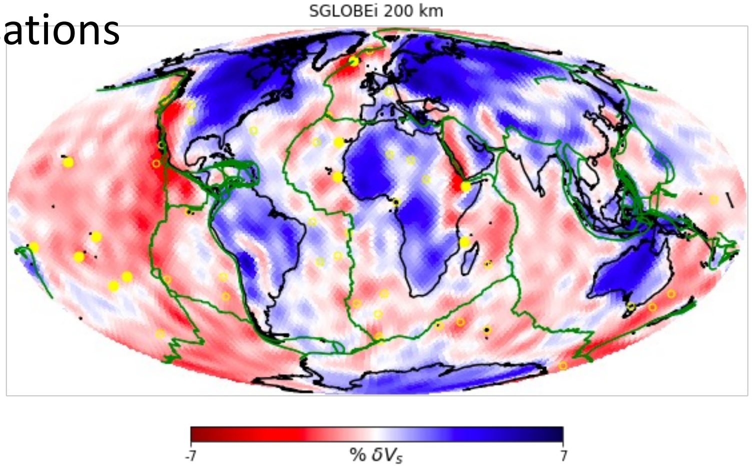
Method

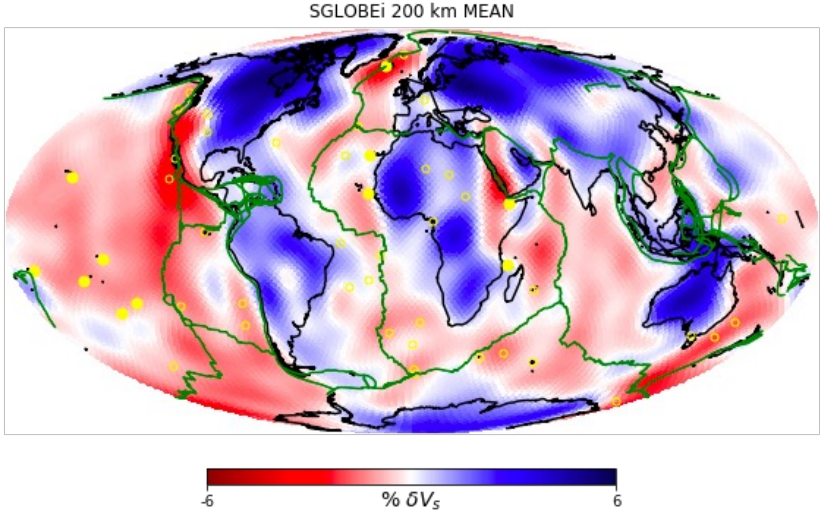
Noise
Realisations

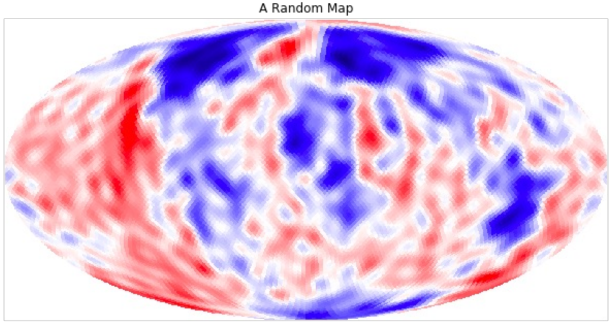


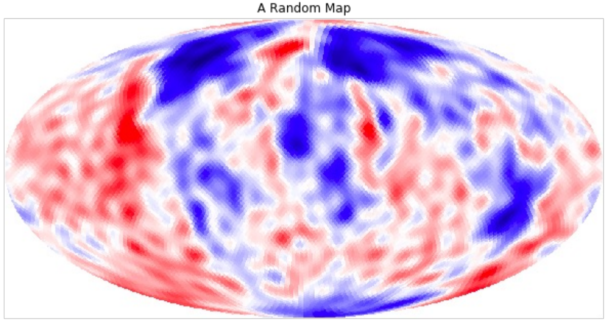
Method

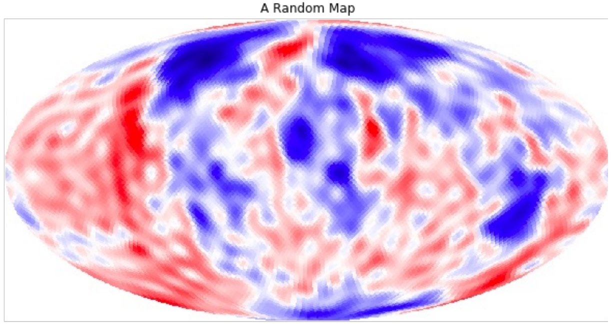
Noise Realisations







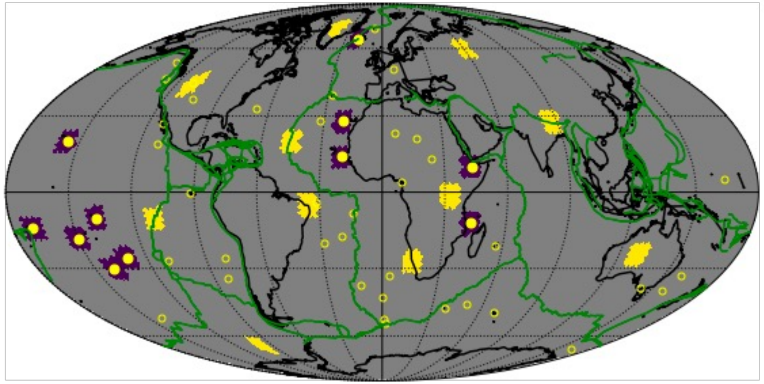


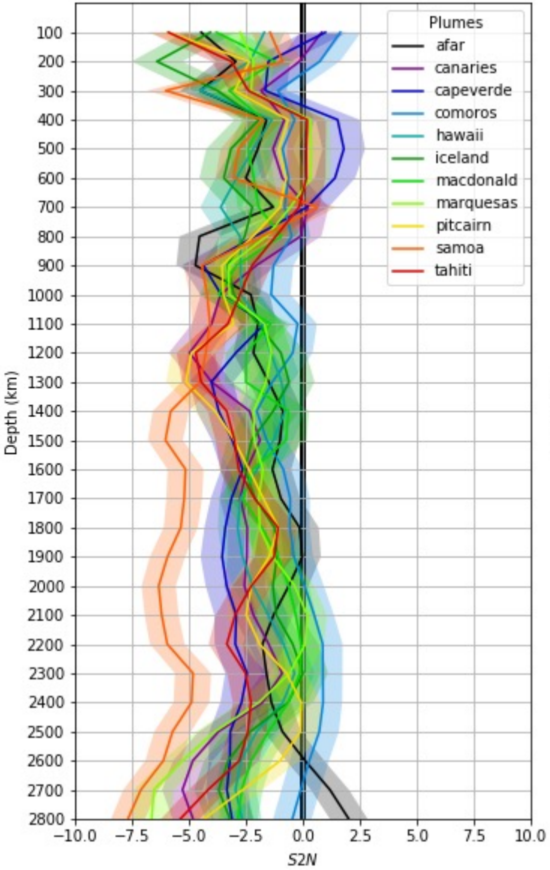


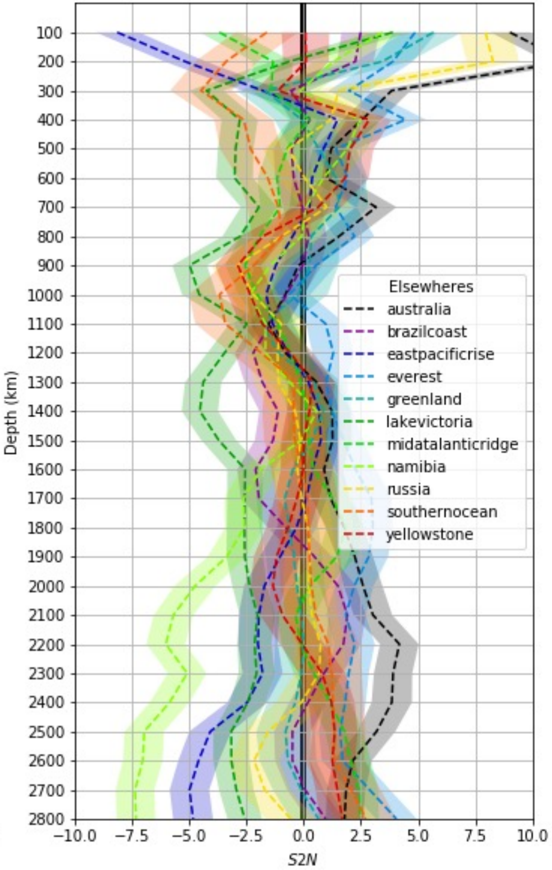
Method

Measure the signal-to-noise ratio in patches in each map

$$S2N = \frac{1}{N_{pix}} \sum \frac{\delta v_s(pix)}{\sigma(pix)}$$



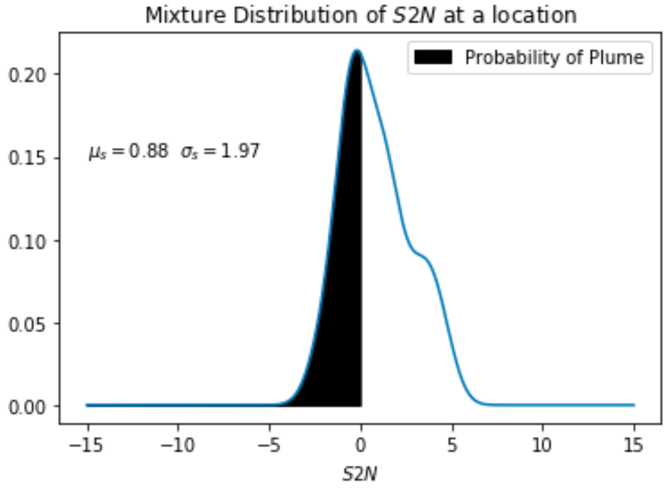




Method

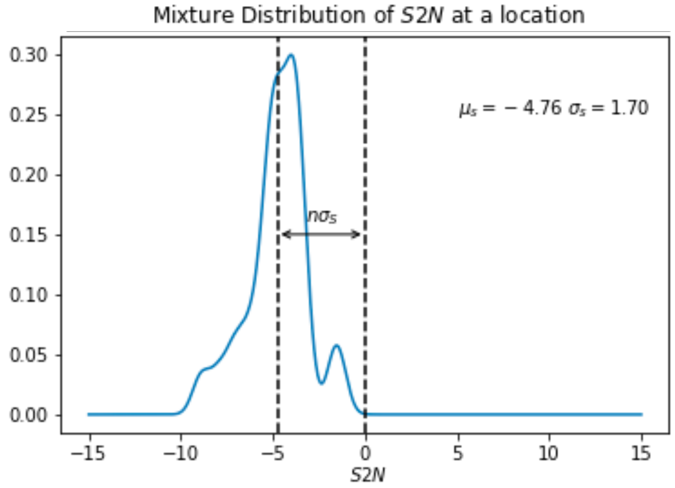
Do some stats

Probability of plume



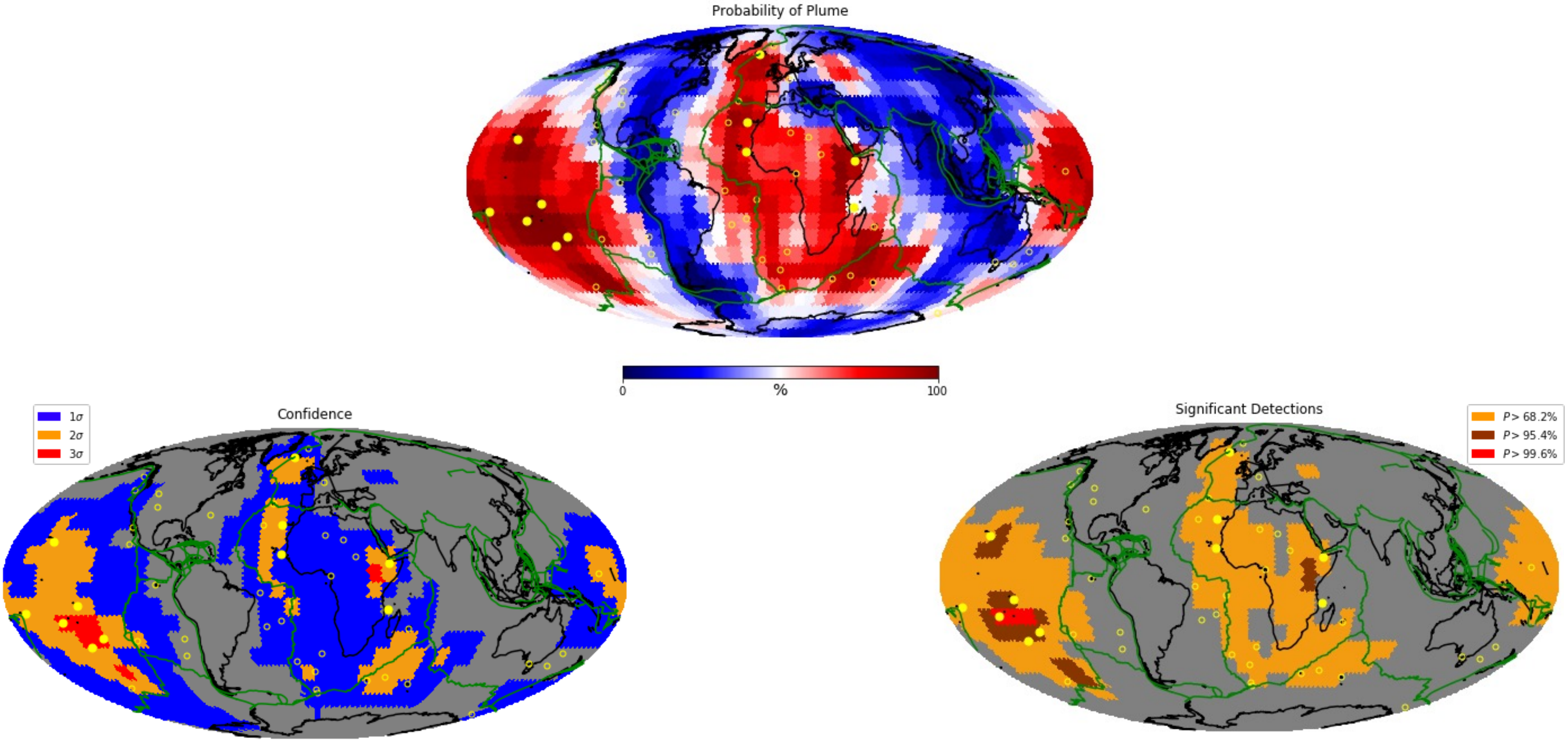
$$P(plume) = \int_{-\infty}^{0} \frac{1}{N_z} \sum_{z} f(S2N|z)\, dS2N$$

Confidence

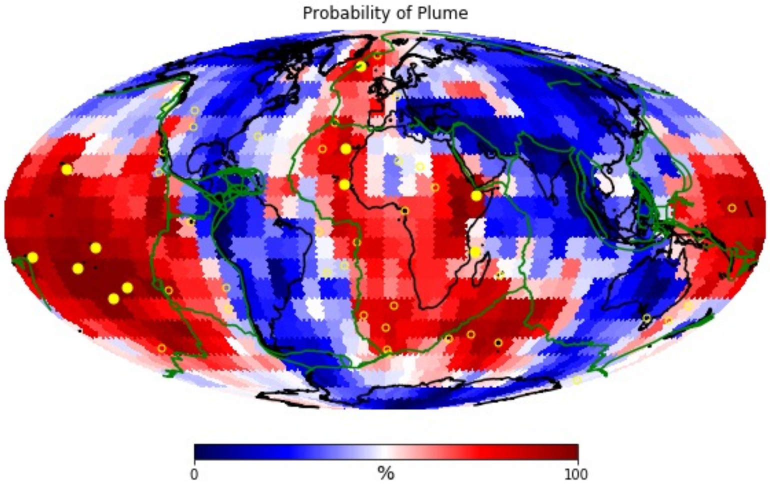


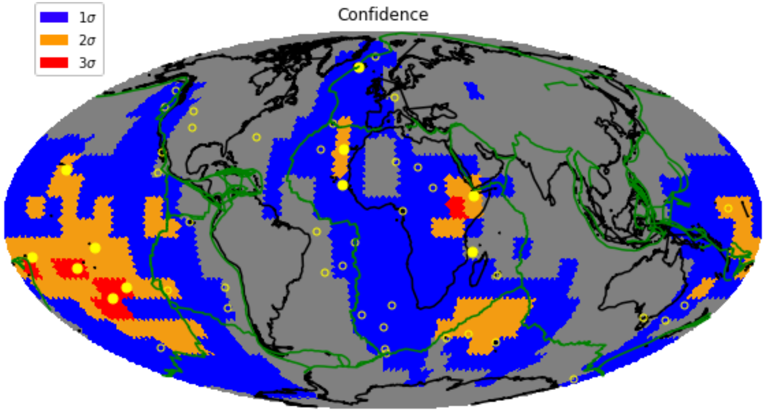
$$n = -\frac{\mu}{\sigma}$$

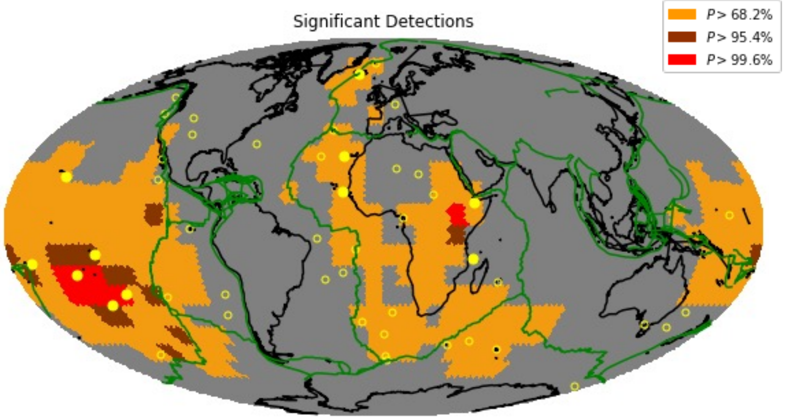
Results – S20RTS



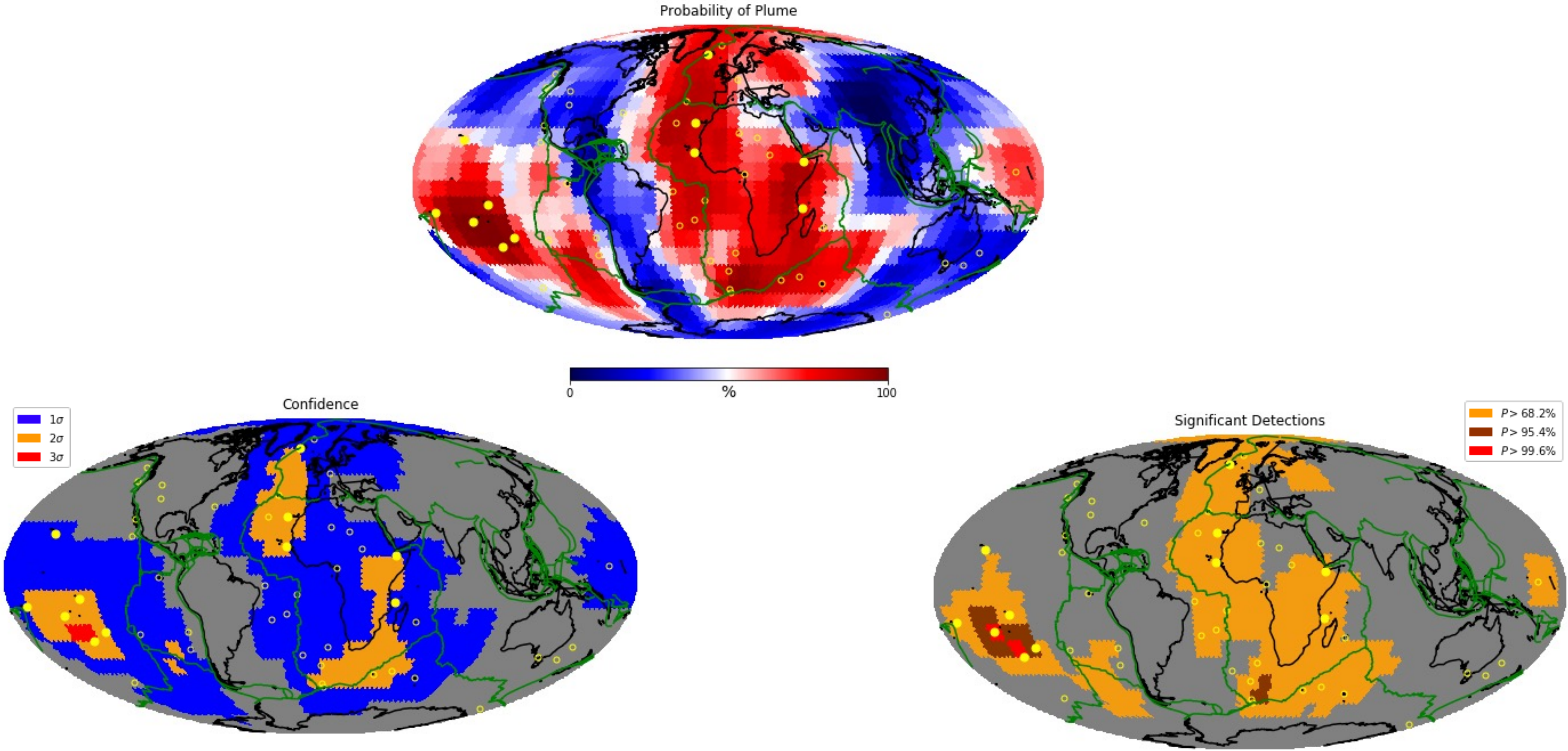
Results – S40RTS



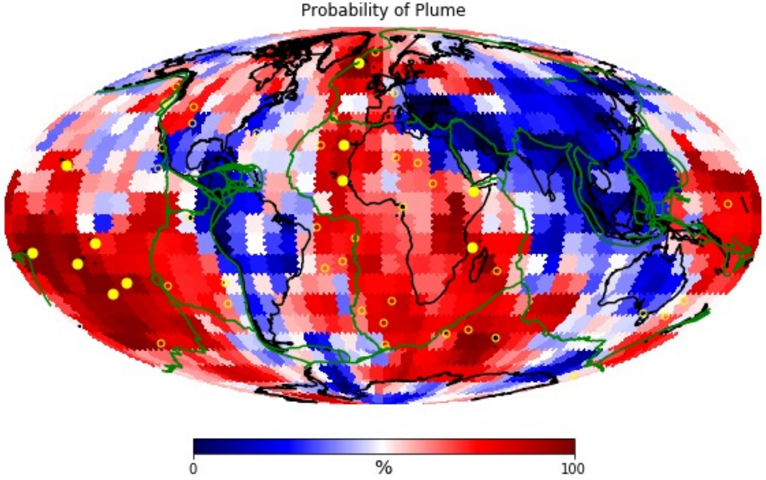


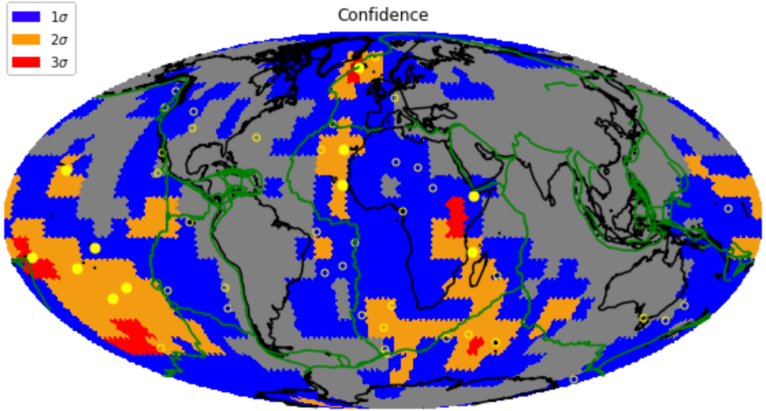


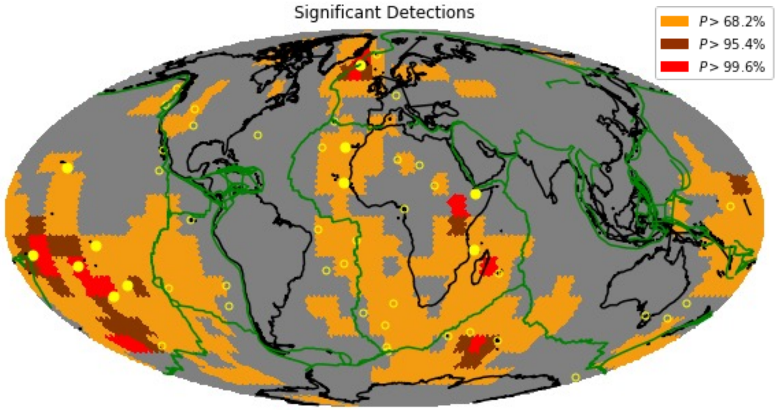
Results – S362WMANI+M



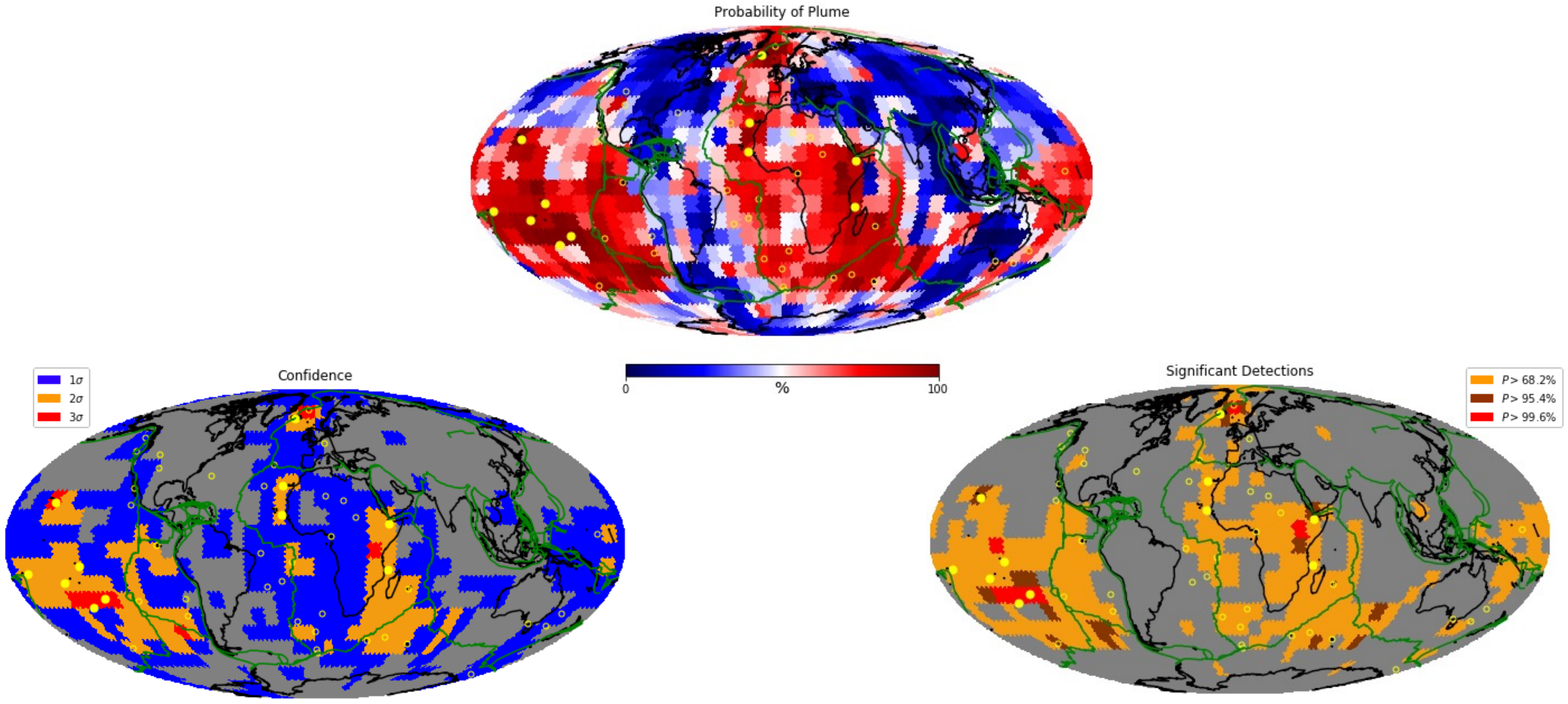
Results – SAVANI



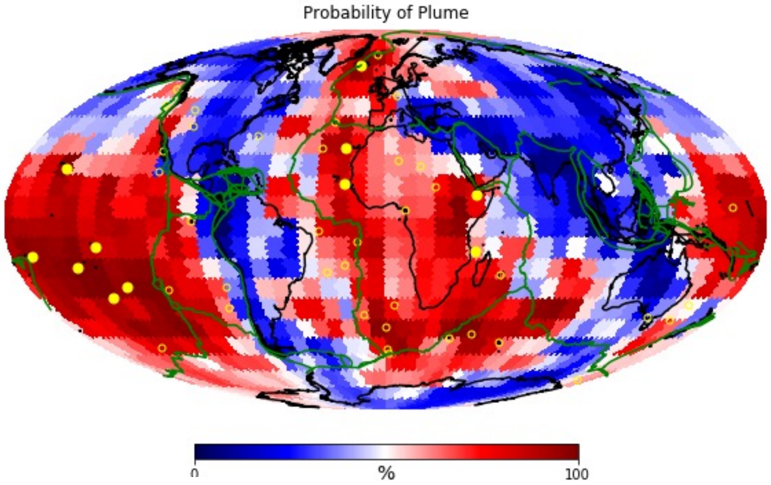


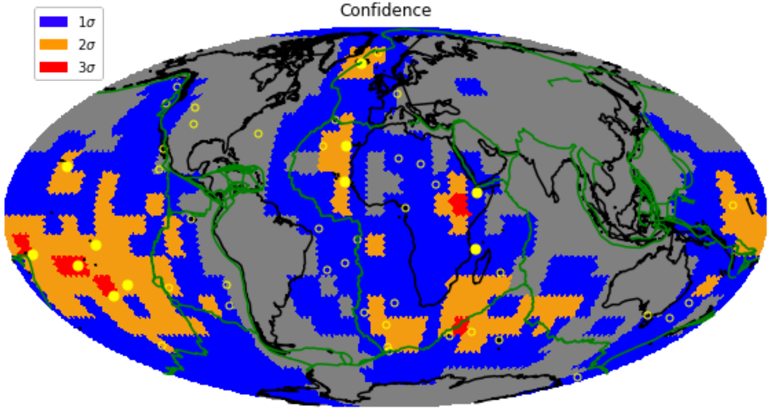


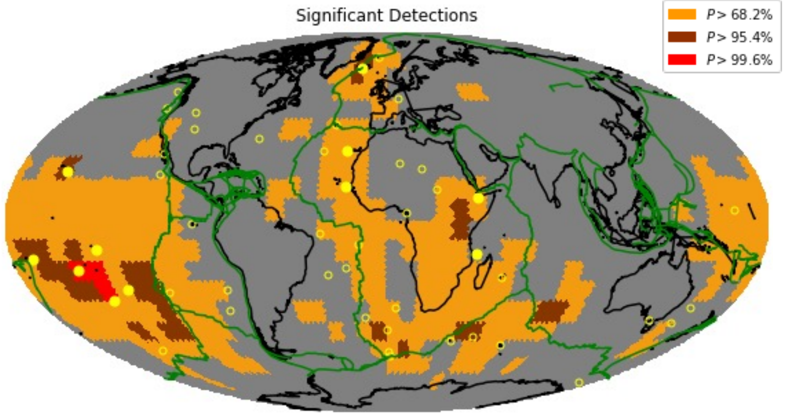
Results – SEMUCB



Results – SGLOBE



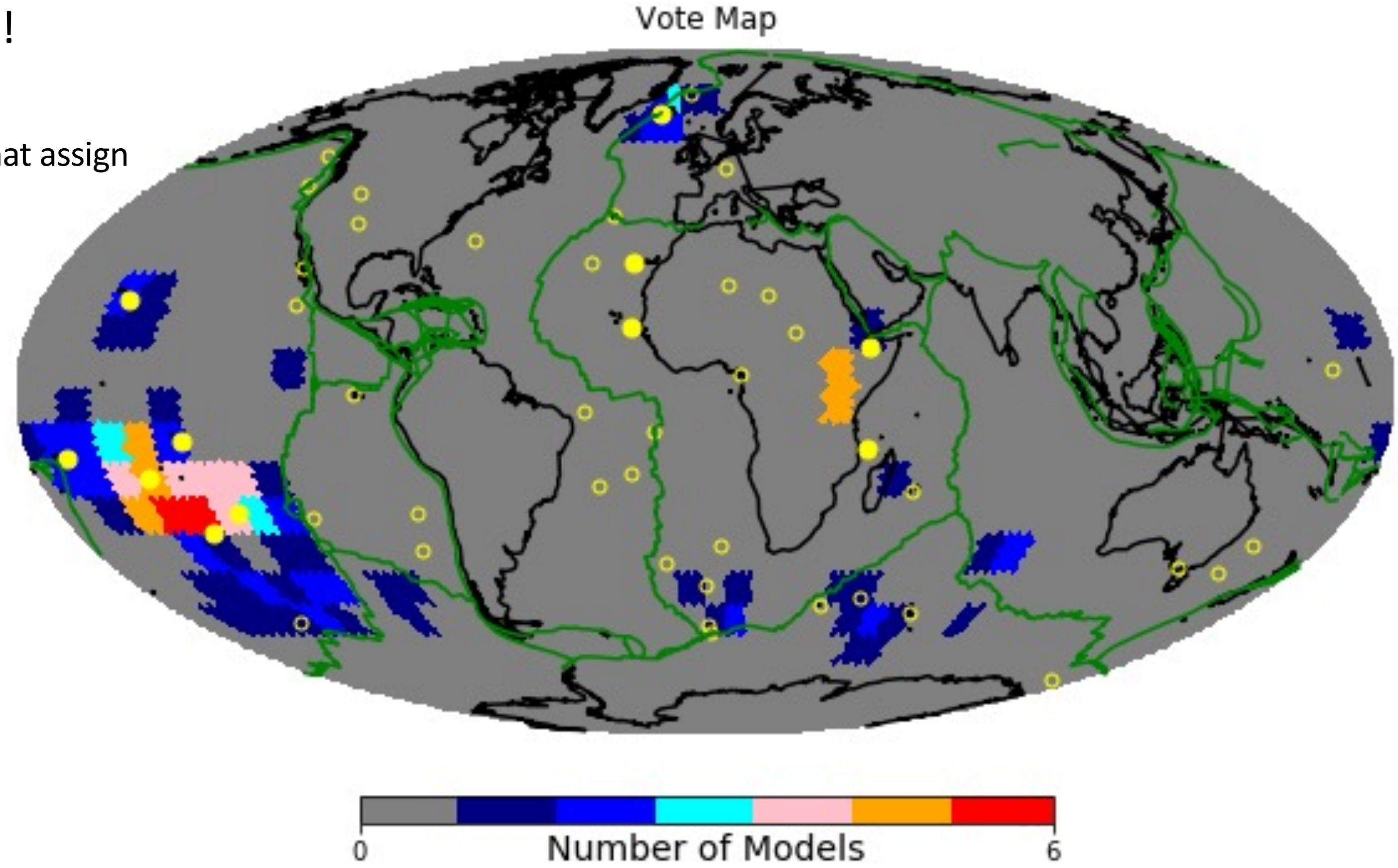




Results

Vote for plumes!

Number of models that assign
$P(plume) > 95.4\%$

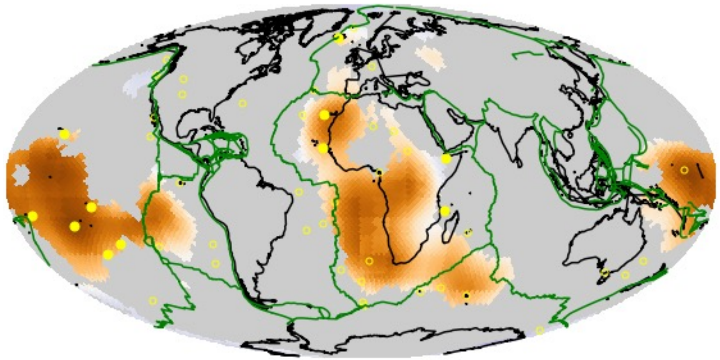


Results

Correlations with LLSVPs

$$c = \frac{1}{N_{pix}} \sum \frac{P(plume)\langle \delta v_s(2800) \rangle}{P(plume)_{rms} \langle \delta v_s(2800) \rangle_{rms}}$$

Cottaar & Lekic, 2016



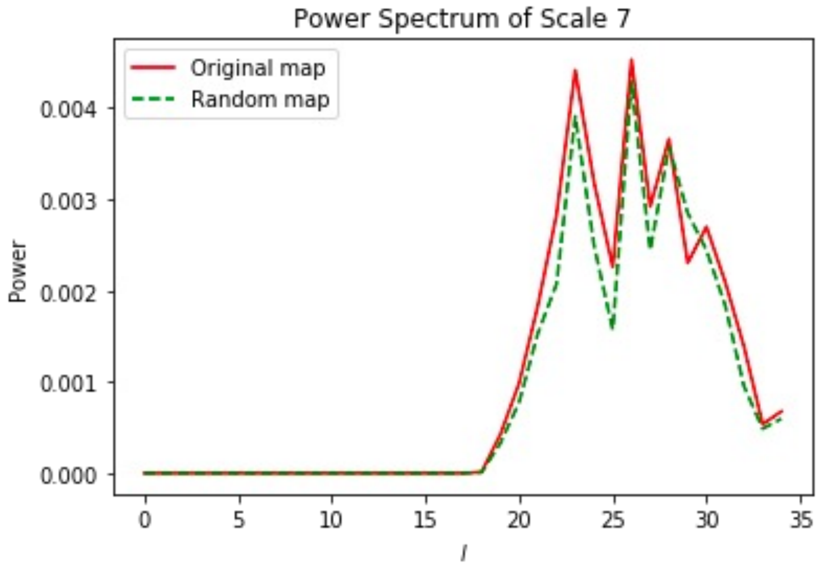
LLSVP	S20RTS	S40RTS	S362WMANI	SAVANI	SEMUCB	SGLOBE
Africa	-0.83	-0.81	-0.84	-0.86	-0.84	-0.83
Pacific	-0.89	-0.87	-0.88	-0.85	-0.90	-0.88
Both	-0.86	-0.84	-0.86	-0.85	-0.87	-0.86
Neither	0.29	0.34	0.00	0.20	0.00	0.27

Conclusions

- Developed a tool to analyse tomographic models
  - To be made publicly available
- Found few plumes consistent between models
- Correlation between probability maps and LLSVPs
  - Should we exclude the last ~10000km in analysis?

Supplementary Slides

Power spectrum simulation



Supplementary Slides

Some equations

$$\left.\begin{aligned} W^{\Psi^{(j)}} &\equiv f \circledast \Psi^{(j)} \\ W^{\Phi} &\equiv f \odot \Phi \end{aligned}\right\} \Leftrightarrow f = \int W^{\Phi}(\mathcal{R}\Phi)d\Omega + \sum_{j_{min}}^{j_{max}} \int W^{\Psi^{(j)}}\left(\mathcal{R}\Psi^{(j)}\right)d\rho$$

$$P(plume|z) = \int_{-\infty}^{0} f(S2N|z)dS2N$$

$$P(plume) = \int_{Mantle} P(plume|z)dz$$

$$= \sum_{z} P(plume|z)P(Z = z)$$

$$= \frac{1}{N_z}\sum_{z} P(plume|z) \equiv \int_{-\infty}^{0} \frac{1}{N_z}\sum_{z} f(S2N|z)\, dS2N$$

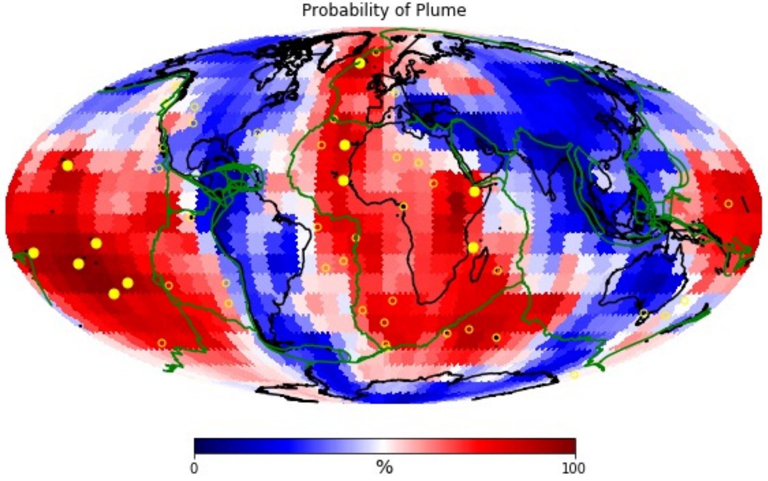
$$C_{fg}(l) = \frac{1}{2l+1}\sum_{m=-l}^{l} f_{lm}g_{lm}^{*}$$

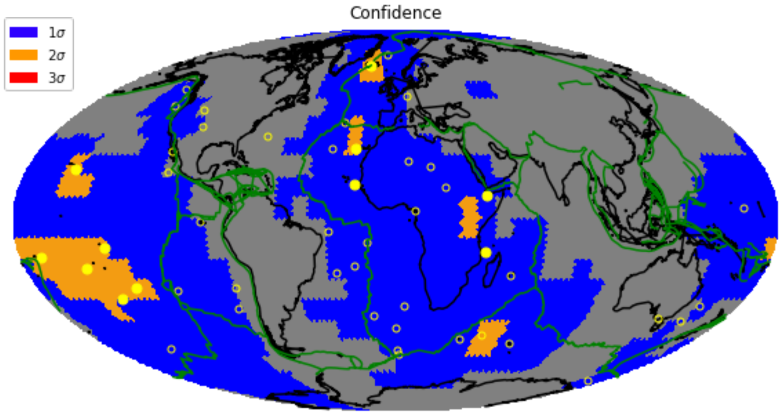
Spherical Harmonic Transform

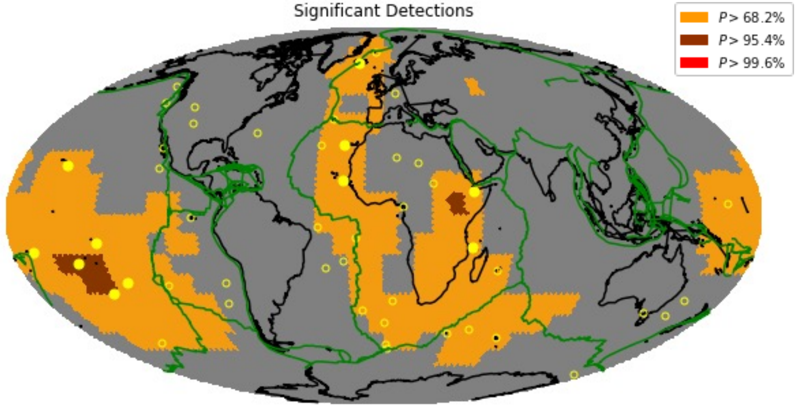
$$(f \star g)(\omega) = \int_{k\in SO(3)} g(k\eta)f(k^{-1}\omega)dk \Leftrightarrow (f \star g)_{lm} = 2\pi\sqrt{\frac{4\pi}{2l+1}} f_{lm}g_{l0}$$

Supplementary Slides

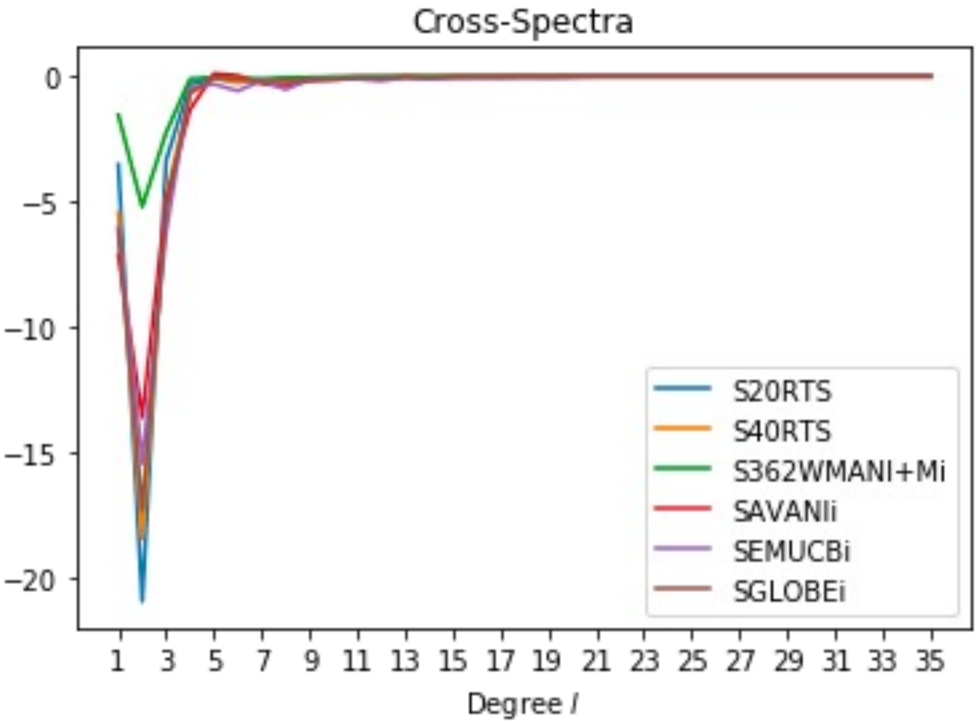
One massive set of S2N







Supplementary Slides



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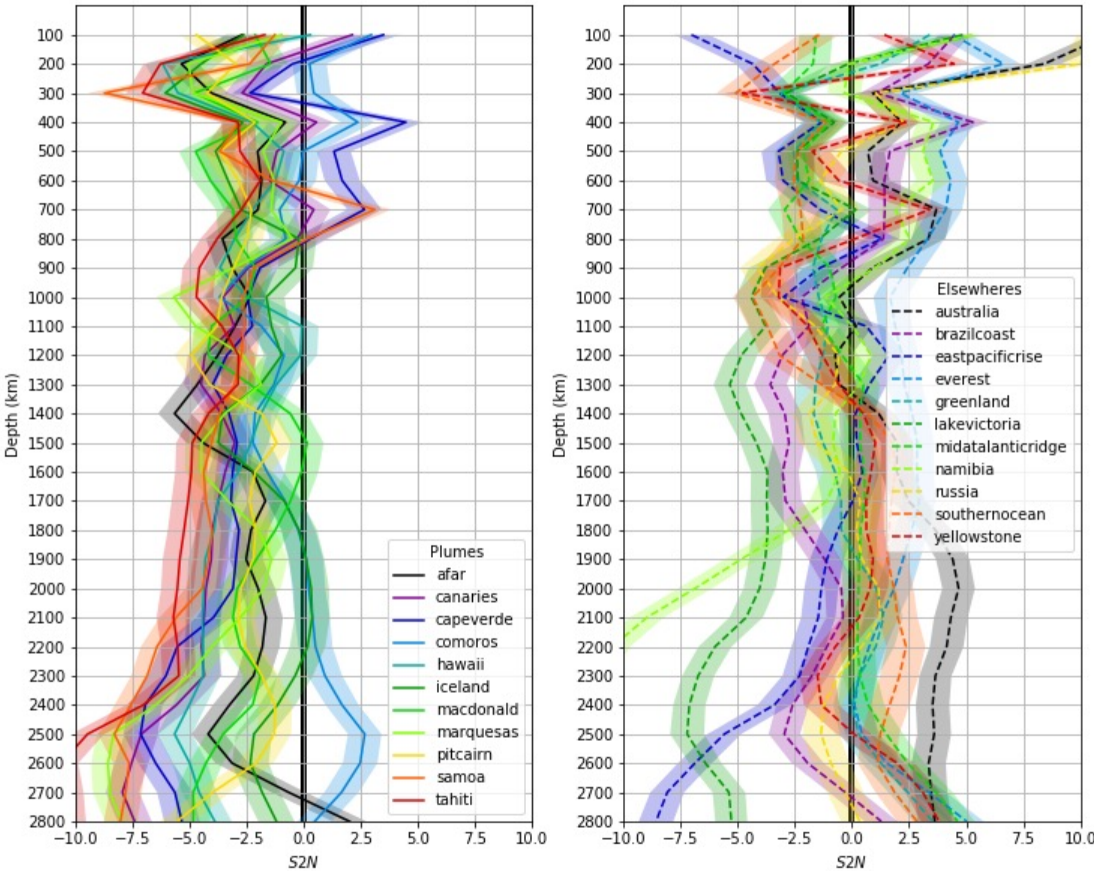
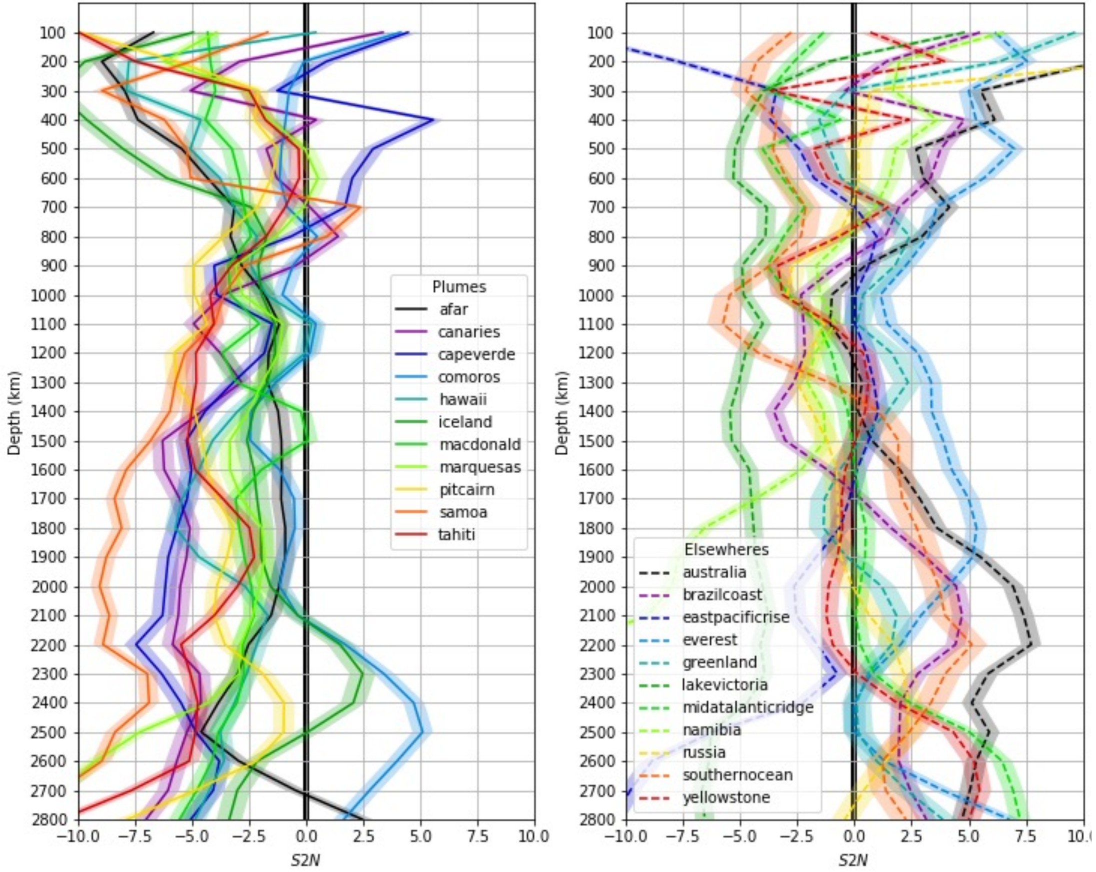


Supplementary Slides



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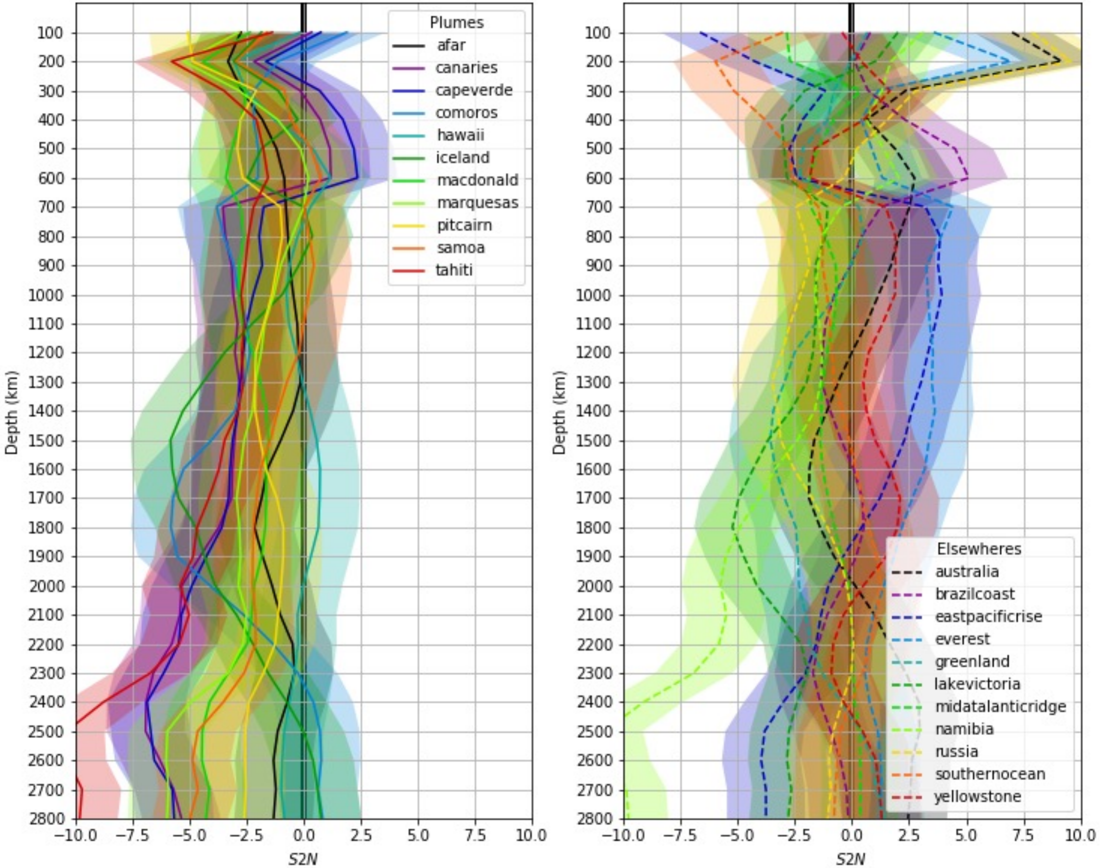

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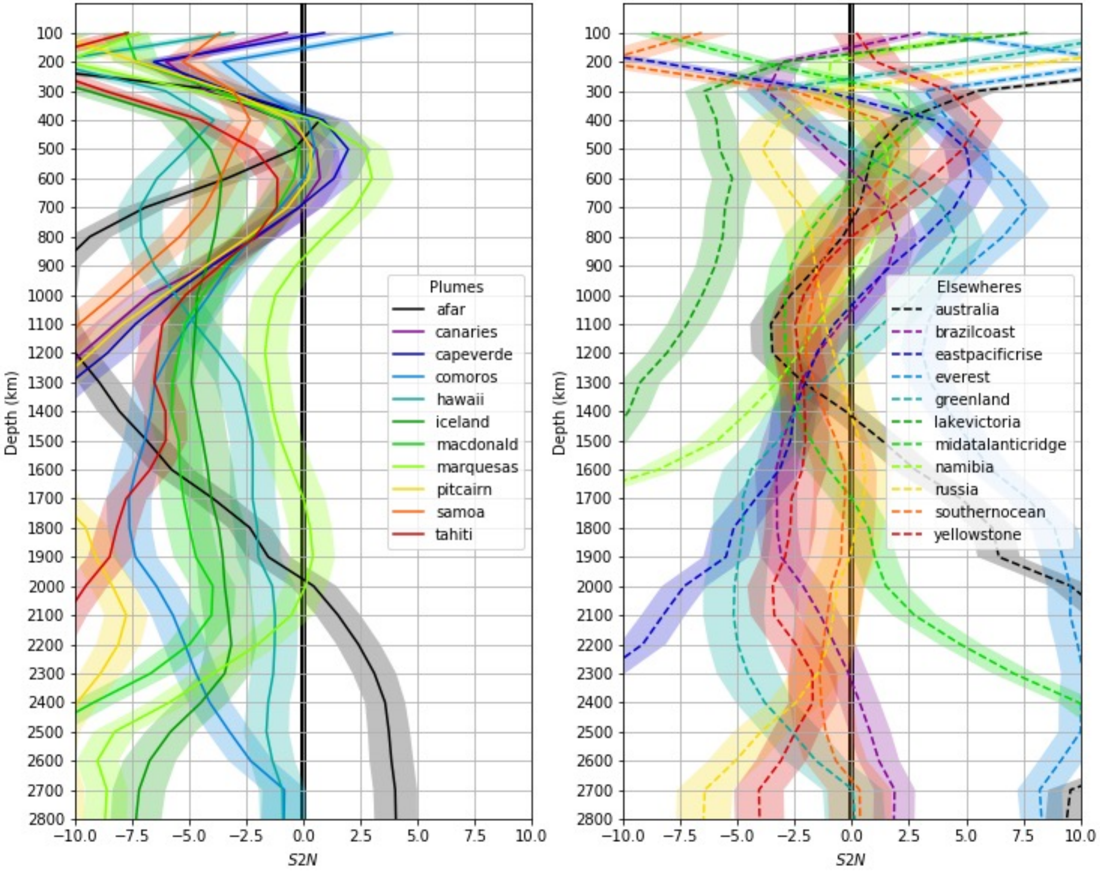
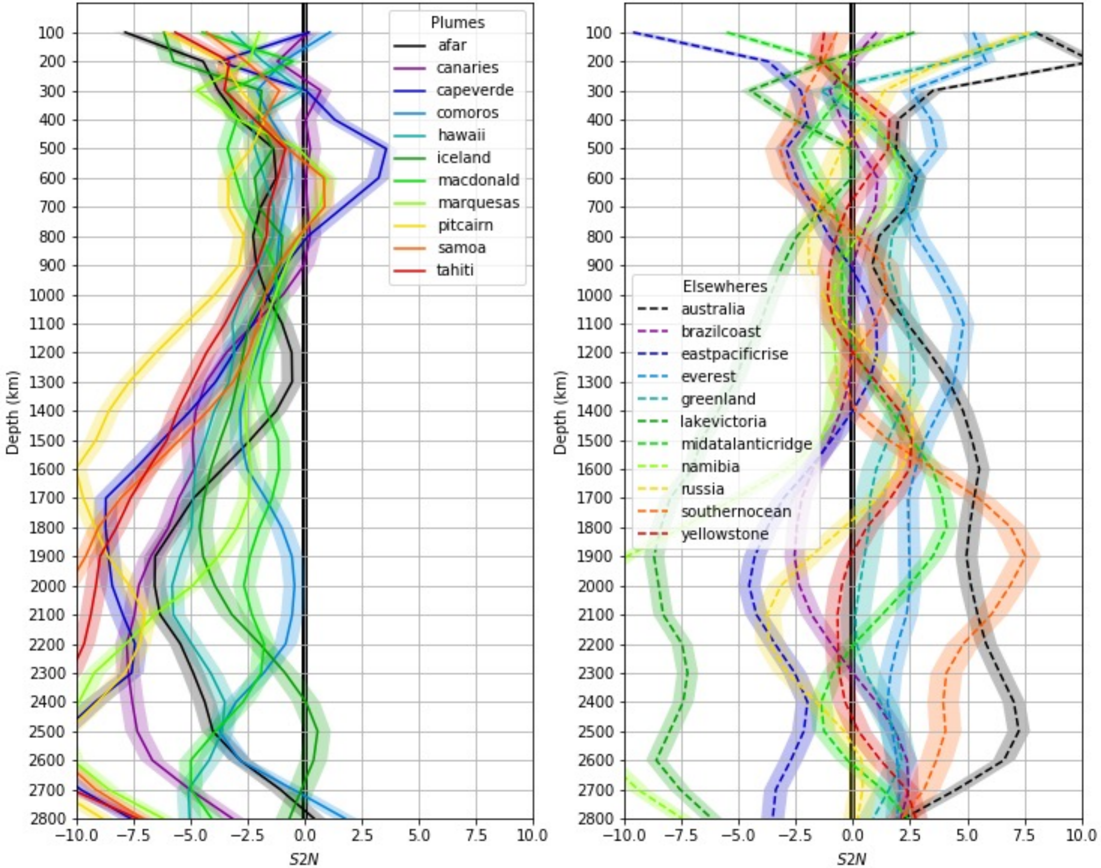
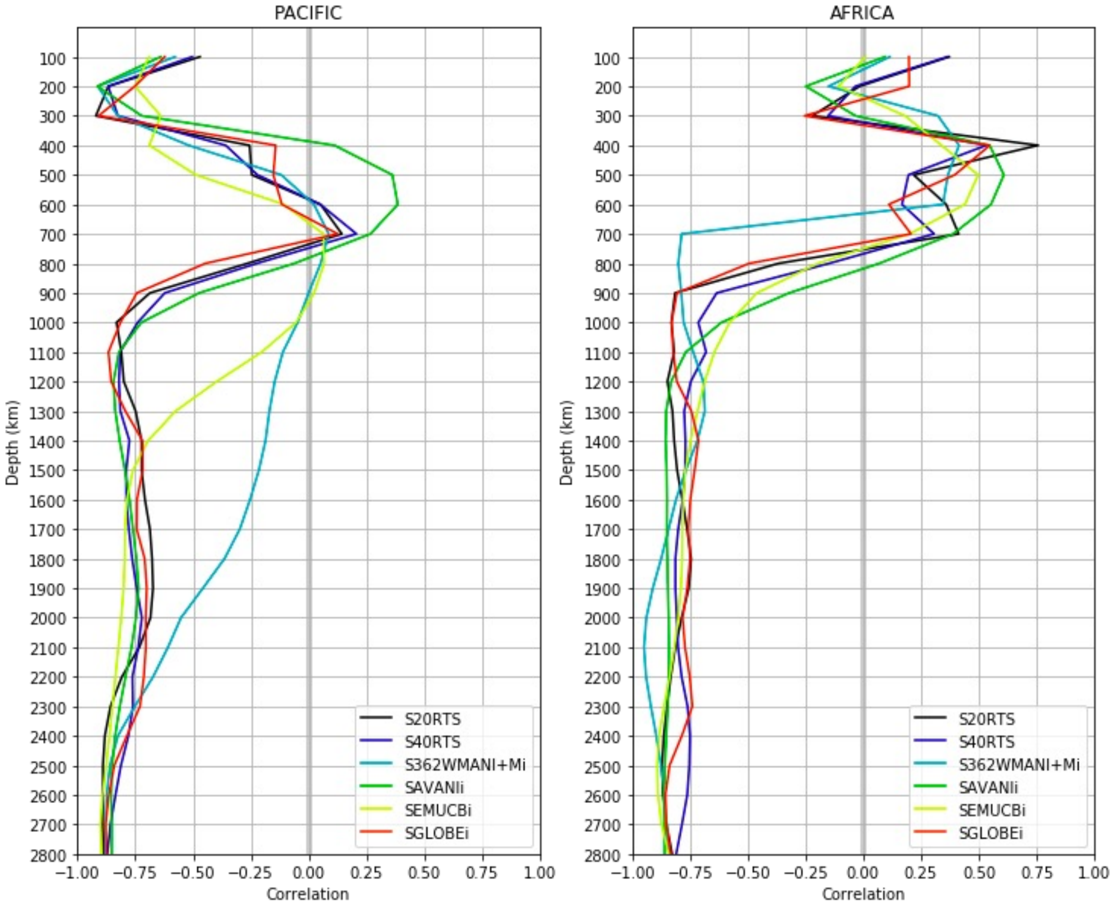


Supplementary Slides



Supplementary Slides

Correlation with each depth slice



Supplementary Slides

Probability calculated up to given depths, correlated with CMB velocity